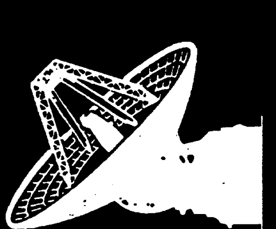
DSN TECHNOLOGY PROGRAM NEWS
JUNE 1995



IN THIS ISSUE

CHAD EDWARDS

This issue of the *DSN Technology Program News* features four articles spotlighting recent research and advanced development efforts within the Telecommunications and Mission Operations Directorate (TMOD). Previous issues of this newsletter have described some of the benefits, as well as the technical challenges, of making the Deep Space Network (DSN) work at Ka-band (32 GHz). Relative to X-band (8.4 GHz), the baseline communications frequency for most current deep-space missions, Ka-band offers roughly a four-fold increase in link performance.

One way to view this link advantage is that a 34-m antenna operating at Ka-band can provide the communications performance of a 70-m antenna at X-band. Alternatively, the Ka-band link advantage can be traded against the power and mass of the spacecraft radio system, enabling smaller, lighter, (and cheaper) microspacecraft with no loss in telecommunications performance.

In this issue, Vic Vilnrotter (Communications Systems Research, Section 331) describes an Array Feed Compensation System, one of several options being investigated to allow our DSN ground antennas to perform well at this shorter wavelength. Since antenna beamwidth scales with wavelength, antenna pointing becomes more challenging at Ka-band. Also, imperfections in the shape of the antenna become more significant at a shorter wavelength,

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NETWORK SIGNAL PROCESSING

KA-BAND ARRAY FEED COMPENSATION SYSTEM

VICTOR VILNROTTER

There is considerable interest in operating the DSN at increasingly higher carrier frequencies to enhance its telemetry capabilities. Higher carrier frequencies yield greater antenna gains and increased useful bandwidth, with reduced sensitivity to plasma effects. However, there are also problems associated with the use of higher frequencies, namely greater sensitivity to antenna deformations and misalignments, more stringent pointing requirements, and increased losses due to weather.

Deformations and misalignments become particularly troublesome on large receiving antennas that are subject to severe gravitational stress, thermal gradients, focusing and collimation problems, and mechanical and wind-induced vibrations. As the antenna attempts to track the source, an inherent time variation is introduced into all of these loss components due to the Earth's rotation and the motion of the spacecraft, even in the absence of wind. The combination of these effects may lead to large pointing errors and severe signal loss, degrading telemetry performance.

Fortunately, the pointing errors can be estimated and most of the losses recovered by a properly designed multifeed "spatial-diversity" receiver that extracts the required information from real-time measurements of signal and noise parameters. The Array Feed Compensation System (AFCS), built in the Network Signal Processing area

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The Array Feed Combiner's ability to adapt to changing distortions in real time results in performance advantages.

for the DSN Technology Program, is a working example of such a receiver.

The Ka-band AFCS has been undergoing evaluation tests at DSS 13, the DSN antenna research facility. The 34-meter antenna is a beam-waveguide (BWG) design: the focal region is translated from the prime focus to a pedestal room directly below the center of the main reflector. In addition to protecting the receiving equipment from the weather, the pedestal room serves as a stationary platform, allowing the equipment to remain fixed as the reflector tips to follow the source. The primary reflector surfaces of large DSN antennas are designed to have a specific shape at a preselected angle on the antenna's elevation axis, called the rigging angle; here, the main reflector panels are forced to conform to design, hence ideal characteristics are obtained. At higher or lower elevations, gravity acts to deform the structure, resulting in deviations from the ideal surface. Thus, we can expect little gain near the rigging angle; most of the benefits of array feed combining should occur outside of this high-performance band.

Figure 1 shows a conceptual design of the AFCS. The signal, assumed to have been generated by a distant spacecraft, is collected by a Cassegrain receiving antenna. Large microwave antennas used by the DSN are of this folded-optical design, relying on the main reflector to collect and focus the received fields and a smaller subreflector to reverse the direction of the focused fields, concentrating them at the Cassegrain focus.

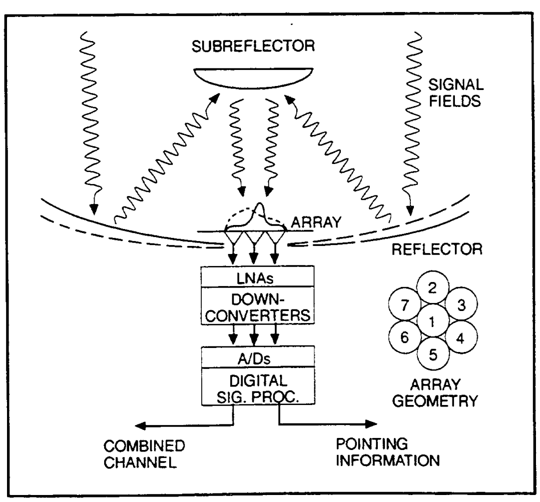

Figure 1. A Comparison of Ideal and Distorted Array Reflector Surfaces

With a BWG configuration, this focal plane can be translated to a more convenient location, such as the pedestal room at DSS 13; however, except for additional BWG losses and possible scaling between the two focal planes, the underlying concepts remain the same.

In the absence of distortions, a properly designed receiving horn collects nearly all of the focused signal fields, while limiting unwanted background radiation. An ideal reflector surface, along with its associated focal-plane signal power distribution, is indicated by the solid curves in Figure 1. The distorted case is illustrated by dashed curves. In general, the reflector surface tilts and deforms, leading to shifted and defocused power distributions in the focal plane. The shift in the peak, which is the result of an effective pointing error, can be eliminated by repointing the antenna. Provided the dimensions of the array have been chosen to encompass this power distribution, all of the significant signal components can be collected by the array. The array channels are "matched" to the signal distribution by continuously adjusting the complex combining weights as the distribution changes. By contrast, a single large horn matched to the distribution at a given elevation becomes mismatched elsewhere, rendering it ineffective outside of its narrow design range. Alternately, matching a single large horn to some average distribution over a wide range of elevations results in relatively poor performance everywhere. Thus, degradations in telemetry performance can be effectively minimized by means of a properly designed real-time array feed receiver that keeps distorted fields confined to the array while combining signal components in the most advantageous manner.

The compensation hardware consists of a maximally compact array of seven circular Ka-band horns, each connected to a cryogenically cooled low-noise amplifier (LNA), followed by a downconverter, analog-to-digital converter (A/D), and digital signal-processing equipment. The signal-processing subsystem estimates relevant signal and noise parameters in real time, computes the pointing error and provides that information to the antenna control system. It also computes optimum combining weights for each channel, combines the weighted signals, and provides a single combined channel to the user. With proper design, the signal quality of this combined channel should approach that of an undistorted antenna, even when significant deformations are present.

Due to the lack of Ka-band spacecraft telemetry, natural sources such as Venus, Mars, and Jupiter have been used. Since the underlying measurements are cross correlations between the channels, the lack of temporal structure in the natural radiation is not a serious impediment. Both tracking and combining data were obtained during this evaluation effort.

Optimum combining weights were derived from the correlation coefficients in real time and supplied to the seven-channel combiner. Combined-channel and central-channel signals were simultaneously available from the combiner, enabling direct comparison of the combined signal with a reference. The correlation coefficients also provided information about antenna pointing, without the need for additional hardware.

The accuracy and repeatability of the array feed pointing algorithm can be seen in Figure 2: while tracking Venus, the antenna was purposely mispointed by a small fraction of a beamwidth (~16 mdeg for this antenna) in both elevation and cross-elevation directions, and the pointing algorithm was used to estimate the applied offsets. With only 2 seconds of integration time, the algorithm provided accurate estimates of each offset, validating the ability of the system to keep the signal distribution centered over the array.

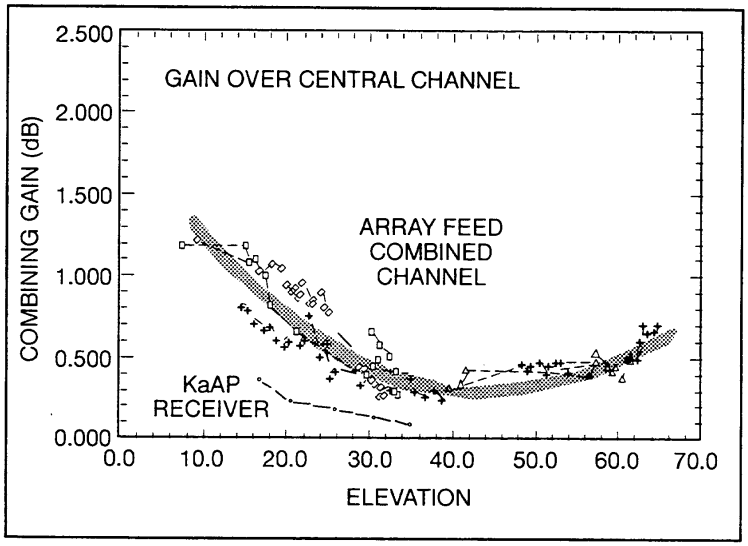

FIGURE 3. COMBINED PERFORMANCE COMPARED TO KAAP RECEIVER PERFORMANCE AT VARYING ELEVATIONS

Combining tests using Venus and Mars revealed significant improvements over the central reference channel, as shown in Figure 3, above. Near the rigging angle, the gain was small, but increased at high and low elevations, as expected. Combiner performance was also compared to the Ka-band KaAP receiver, a conventional single-horn design optimized for the 34-meter BWG antenna (see *DSN Technology Program News*, March 1995). After accounting for design differences between the two systems, the performance of the conventional receiver was referenced to the array feed central channel, facilitating comparison with the combined signal. The array feed combiner's ability to adapt to changing distortions in real time results in substantial performance advantages over the conventional single-horn receiver: a performance gain of about 0.7 dB was observed at 20-deg elevation, while even greater gains were achieved close to the horizon.

Significant Ka-band performance improvements have been demonstrated by array feed combining on a relatively rigid 34-meter antenna using broadband natural sources. This technique should yield even greater improvements on the DSN's older and larger 70-meter antennas, which suffer unacceptable losses at Ka-band frequencies. As Ka-band telemetry becomes available through SURFSAT and KABLE-II, array feed compensation efforts will be directed towards development of a fully operational "turn-key" system. The inherent ability of the AFCS to extract pointing information without the need for mechanical scanning, while recovering signal losses through real-time signal-processing techniques, greatly enhances the DSN's ability to use Ka-band frequencies for future missions.

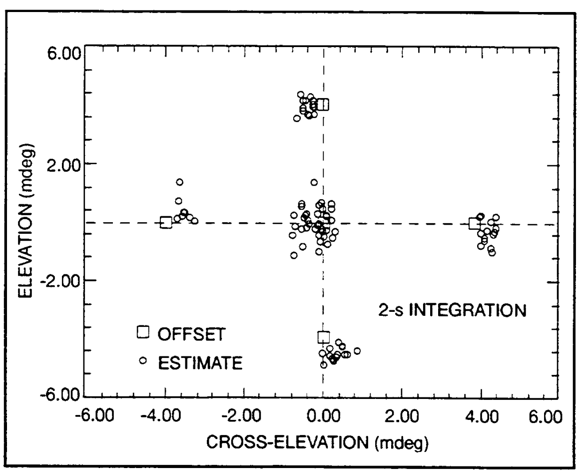

FIGURE 2. ARRAY FEED POINTING ALGORITHM TEST AT VENUS, DOY319